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AN INSTRUMENT FOR THE BEDSIDE QUANTIFICATION OF SPASTICITY: A PILOT STUDY

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Abstract- **Spasticity is a velocity-dependent phenomenon; the quicker the limb is moved the more resistance is encountered. A compact, portable instrument was constructed for recording the angle at the knee, the rate of change of angle (angular velocity) and the force encountered at the ankle when the limb was flexed. A pilot study was performed on 5 normal volunteers and 5 patients with spasticity. A preliminary index of spasticity was extracted from the measurements, being 0.163±0.059 N.s/deg (mean±SD) for the patients and 0.052±0.030 N.s/deg for the normal group.**
***Keywords* - Tone, Spasticity.**

I. Introduction

A number of common conditions affecting the central nervous system including stroke, head injury and Parkinson's disease are complicated by abnormalities of tone in the limbs. Tone is defined as the resistance encountered when passively moving the limbs and the two main types of increased tone are spasticity and rigidity. Spasticity is a velocity-dependent phenomenon; the quicker the limb is moved the more resistance is encountered [1]. It is also non-uniform in that the resistance encountered is not the same throughout the whole range of movement. This contrasts with rigidity which is non-velocity-dependent and uniform. These clinical characteristics allow the phenomena of spasticity and rigidity to be detected at the bedside and their presence or absence provide useful diagnostic clues.

Whilst the characteristics of spasticity are invaluable diagnostically, their quantification using objective measures on a ratio scale does not form part of routine clinical practice and large trials of anti-spasticity drugs have relied on insensitive ordered categorical scales such as the Ashworth scale [2,3]. A portable and user-friendly device which could detect and quantify abnormalities of tone would be an invaluable adjunct to the clinical assessment and would allow a more comprehensive assessment of the effects of different interventions including physiotherapy, hydrotherapy and medication. To ensure that the relevant data were collected a device was designed with three prerequisites in mind, namely the need to record the angle at the knee, the rate of change of the angle at the knee (angular velocity) and the force applied at the ankle.

II. Methodology

A. Instrument

The instrument† developed was a goniometer with angle and force transducers (fig 1). Angle was measured by a potentiometer in the hinge positioned at the knee. Force was measured by a force transducer in the handle, positioned at the ankle, with which the examiner flexed the knee. The instrument incorporated adjustable features to accommodate different sizes of leg and degrees of varus and valgus deviation. The potentiometer and force transducer were powered from stabilized voltage supplies and the analog signals were measured with a data acquisition card (DAQCard-AI-16XE-50, National Instruments) in a laptop computer. Data acquisition and processing was performed with Matlab v5.3. Angle and force were sampled at 500 Hz. Angular velocity was computed by differentiating the angle-time record and smoothing with a 5-point running-average filter.

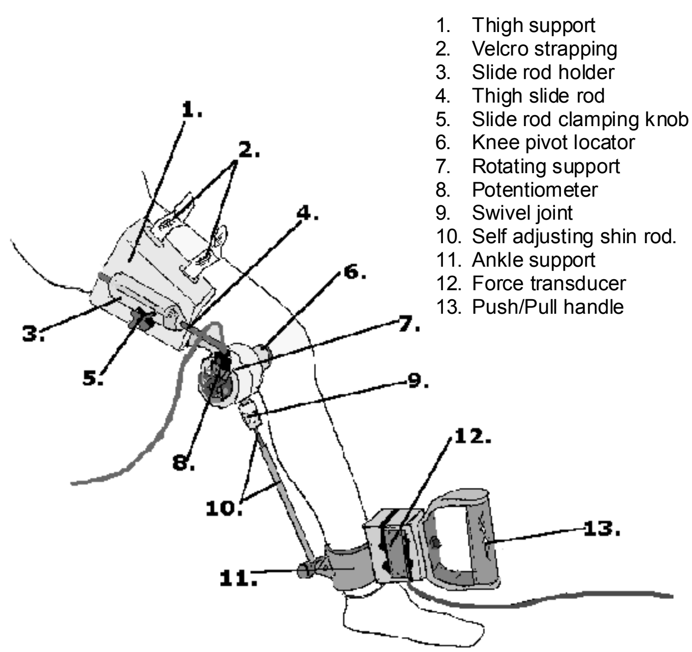

Fig. 1. The gonimeter attached to the knee.

B. Clinical measurements

Five patients with a stable neurological condition complicated by spasticity of the lower limbs and five normal subjects from hospital staff were recruited for examination (Table I). After explaining the experiment to the subjects, all gave written consent.

With the subject supine on the bed with the head and trunk elevated to about 20 degrees the device was applied to the lateral aspect of the right leg. The instrument was positioned at the

† The Cardiff Flexator: Patent Pending

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Abstract

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lateral aspect of the knee joint and adjusted appropriately. The lower end of the device was secured just above the lateral and medial malleolus. Having checked that the patient was comfortable, a few trial runs were performed. If no discomfort was reported the measurements proceeded.

In the experiment the examiner attempted to reproduce the normal examination of tone but with the device applied to the leg. This involved the examiner lifting the whole leg with the left hand under the knee and the right hand holding onto the handle anterior to the lower tibia. In the normal way the hip and knee were flexed and extended avoiding, if possible, contact of the heel with the bed covers. The examiner flexed the leg at three different speeds over a 10-20 s period during which data was acquired. Throughout the experiment the subject was invited to volunteer any discomfort or symptoms that arose.

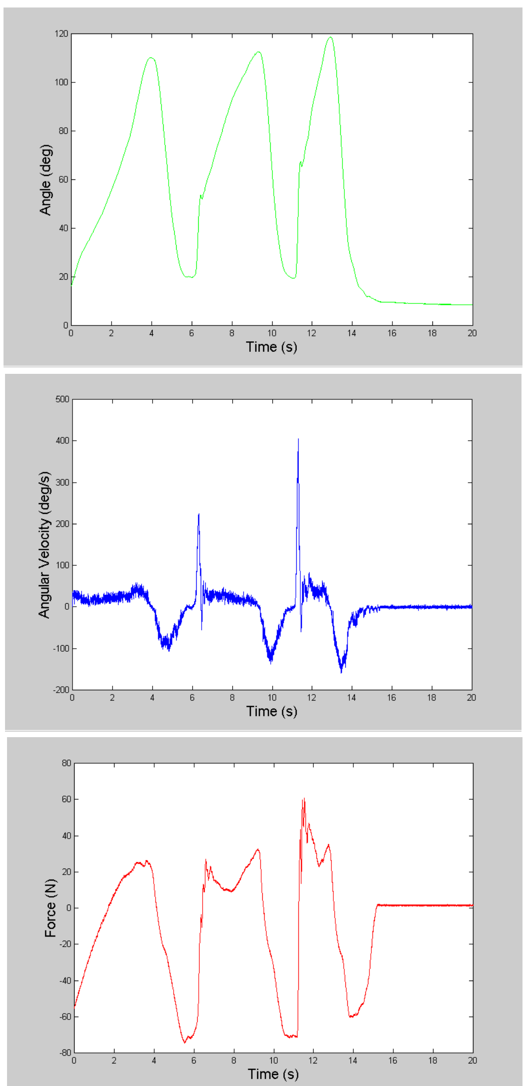

Fig. 2. Traces of angle, angular velocity and force displayed against time for Subject 2.

III. Results

A. Raw data

Fig 2 shows recorded traces of angle, angular velocity and force against time for one of the patients (Subject 2). The traces show the three leg manipulations, each starting at approximately 20 degrees of flexion and flexing to 110 degrees or more. The velocity trace shows the progressive increase in peak velocity effected. Positive velocity represents increasing flexion and negative velocity represents increasing extension of the leg. It can be seen that the peak applied force also increased. Positive force indicates that the examiner was pushing so as to flex the knee and negative force indicates where the examiner was not pushing but supporting the weight of the lower leg. The state of relaxation of the subject was an important factor in obtaining good quality data.

B. Force-angle-velocity plot

The significance of these measurements can more easily be visualized by combining angle, angular velocity and force on the same plot. Fig 3 shows the velocity measurements from Subject 2 plotted against angle. The color of the trace is modulated to indicate force. Each flexion and extension (bending and straightening) forms a loop on the plot. The first flexion

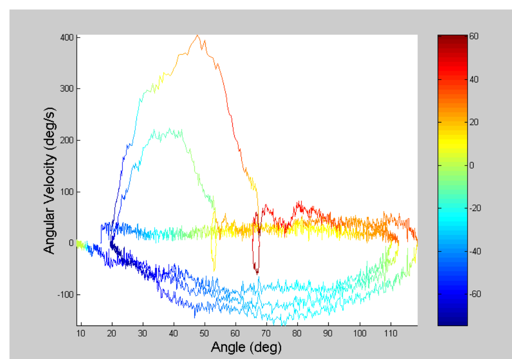

Fig. 3. Force-angle-velocity plot for Subject 2 (patient). The color scale represents applied force in Newtons.

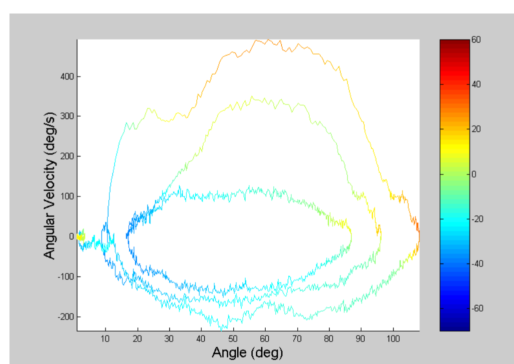

Fig. 4. Force-angle-velocity plot for Subject 10 (normal subject).

reached a peak velocity of about 30 deg/s and the force reached 20 N until the maximum flexion of 108 degrees was attained; at this point the force rose slightly as the examiner pushed against the limit of bending of the knee joint. The next flexion reached a higher velocity, approximately 220 deg/s but now, at an angle of about 43 degrees, the velocity fell rapidly and the force rose to 30 N caused by an increase in the resistance to passive movement of the limb. There was then a recovery of the velocity until again the maximum flexion of 110 degrees was reached. The third flexion, at a still higher velocity, reached 400 deg/s. Now the drop in velocity and increase in muscle resistance were even more marked, with the force reaching 80 N. The maximum flexion was higher, about 118 degrees, as the examiner continued to apply a large force. These results clearly show the velocity-dependent nature of the resistance to passive movement encountered in spasticity, and its non-uniformity with angle of flexion.

Fig 4 shows a force-angle-velocity plot for one of the normal subjects. Here there was no sudden drop in velocity in mid flexion and, ignoring angles near the limit of flexion of the leg (>100 deg), the maximum force attained was only about 25 N even for a peak velocity of almost 500 deg/s. The maximum force now occurred during the acceleration phase of the leg, between angles of 40 to 70 degrees, whereas in the patient (fig 3) the maximum force occurred during a deceleration.

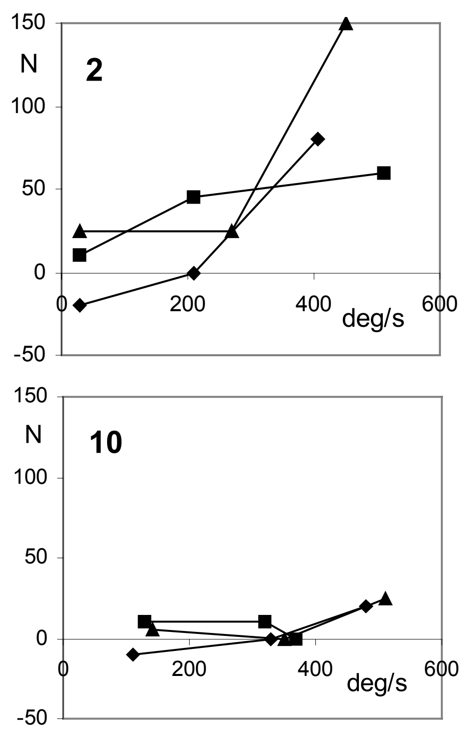

Fig. 5. Maximum applied force following the main peak in angular velocity plotted against peak angular velocity for Subjects 2 (patient) and 10 (normal subject). Points in each set are joined by lines.

C. Index of spasticity

These observations suggest a way of quantifying spasticity from this data. The maximum force attained following the main peak in angular velocity was plotted against the value of the peak velocity. This meant that only the deceleration phase was included. Fig 5 shows the values for the same patient and the normal subject as above. Three sets of three leg flexions at varying speeds were included in each case. The extension phases of the manipulation of the leg (i.e. the negative-velocity portions of the curves in figs 3 and 4) were not included in the analysis.

For the patient, a general increase in peak force with peak angular velocity is seen from Fig 5, whereas for the normal subject the changes were much smaller. A linear least-squares fit was carried out for all 9 points in each plot and the gradient of the fitted line for all the subjects is given in Table I. The mean gradient (±SD) was 0.163±0.059 N.s/deg for the patients and 0.052±0.030 N.s/deg for the normal group. An unpaired t-test showed that this difference was highly significant (P<0.01).

TABLE I

Subject	Sex	Age	Diagnosis	Gradient (N.s/deg)
1	F	36	Multiple sclerosis	0.058
2	M	41	Multiple sclerosis	0.207
3	M	28	Multiple sclerosis	0.227
4	M	47	Hereditary spastic paraparesis	0.151
5	M	44	Multiple sclerosis	0.173
6	M	47	Normal subject	0.004
7	M	48	Normal subject	0.076
8	M	18	Normal subject	0.042
9	M	39	Normal subject	0.091
10	M	49	Normal subject	0.047

IV. DISCUSSION

The gradient of the linear fit to the peak force/peak angular velocity data was generally much higher in the patients than in the normal subjects, reflecting the fact that the muscle resistance was velocity-dependent in spasticity. One of the patients (Subject 1), although exhibiting clear spasticity clinically, gave a value of gradient within the normal range. This was the only female subject studied so far and the lower value obtained could be reflecting sex and muscle strength differences. These factors should now be investigated as part of a larger study. Nevertheless, the calculation of gradient in this way could form the basis for an index of spasticity from the data obtainable with this instrument.

In all patients the increase in muscle resistance at a certain angle of flexion was followed by a "give" in the muscle with a sudden increase in angular velocity at a reduced applied force. This is evident in example shown in fig 3 at angles of 52 and 68 degrees for the medium- and high-velocity traces respectively.

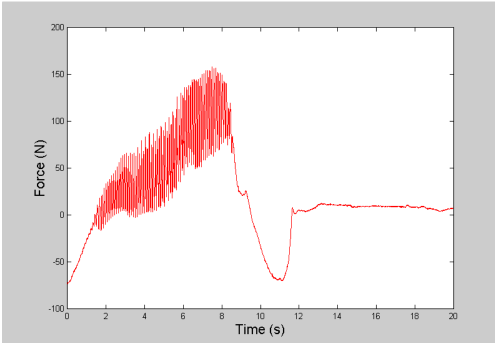

Fig. 6 Force-time trace for Subject 2 on the fourth set of manipulations, showing clonus.

One of the patients (Subject 2) showed an overall increased stiffening of the leg as the tests progressed, exhibiting clonus which was clearly seen in the force-time trace as a 10 Hz oscillation (Fig 6). At this stage the examiner could no longer complete the flexing tests on the leg. In contrast, other patients reported an improvement in the leg as the tests progressed and the maximum muscle resistance encountered was seen to decrease.

All these factors could be extracted from the data obtained and are potentially useful measures of muscle tone.

V. Conclusion

A compact, portable instrument, for use at the bedside, has been developed for quantifying muscle tone in the leg from measurements of angle of flexion, angular velocity and applied force. A preliminary index of spasticity was extracted from the measurements but potentially a number of alternative indices could be used and may allow changes in spasticity to be monitored more accurately. With a suitable adaptation of the instrument, the technique could also be applied to the arm.

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